Digital Simulation of Full Scale Static Test of Aircraft

XU Ze[1,2]
(1. Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China)
(2. Chengdu Aircraft Design and Research Institute, Chengdu 610041, China)

Abstract: Full scale aircraft static test is a very important process of aircraft design, it is costly and time consuming. The testing accuracy and validity mainly depend on the rationality of the test scheme design. When the aircraft is being tested, the specimen's safety mainly depends on monitoring and understanding the testing data by way of evaluating the coherence with the digital simulation data synchyonously. The test digital simulation can aid realizing above requirements and improving the test efficiency significantly during test scheme design stage or testing stage respectively. The key technologies and the solving methods of test digital simulation are presented and the application example is given.

Key words: the mechanics of flight vehicle; aircraft structure; static test; digital simulation; full scale

全尺寸飞机结构静力试验数字仿真. 许泽. 中国航空学报(英文版), 2005, 18(2): 138－141.

摘　要: 全尺寸飞机结构静力试验是飞机结构研制的重要环节,需大量的财力和时间投入。试验结果的精度和有效性主要依赖于试验实施方案设计的合理性; 试验件的安全主要依赖于试验时同步地对试验测试数据的监控和与数字仿真结果的一致性评估。全尺寸飞机结构静力试验数字仿真能够辅助实现上述要求,显著提高试验效率。介绍了全尺寸飞机结构静力试验数字仿真的关键技术及解决方案并给出了应用实例。

关键词: 飞行器结构力学; 飞机结构; 静力试验; 数字仿真; 全尺寸

文章编号: 1000-9361(2005)02-0138-04　　中图分类号: V216.1　　文献标识码: A

In order to decrease the cost and period of aircraft design and to improve the reliability of first-time successful design, the digital simulation technology is being developed and playing a very important role in each phase of aircraft design. Due to the application of simulation, the design cycle of developing a new type is shorten from a few decades to a few years. The full scale aircraft static test is a very important and necessary process to verify the strength and stiffness of aircraft structure. Generally, a quite few of general load cases will be tested on the same specimen for the sake of simulating the diverse flight maneuver. Full scale static test is complex, costly and time consuming. The full scale aircraft static test digital simulation technology is a good solution to guarantee the test validity, accuracy and safety of the tested specimen. The full scale aircraft static test digital simulation technology contains two aspects. The first part is the establishment of digital simulation model of tested specimen, including the aircraft platform structure, system accessories such as engine, rotational actuator and testing support rigs *etc.*, by way of finite element method as the digital simulation database and then linking the database to the test data measuring facility by network. The second part is the development of quick data coherence evaluation system to quickly deal with the test data and compare the coherence of test data and simulation data. In the period of test scheme design stage, the technology can aids realizing the optimized test scheme, reducing the number of testing load cases and bringing the simplest test scheme into effect. During the test stage, it can evaluate the coherence between the test data and simulation data with the change of each loading step, the trends is visually displayed on monitoring screens, and it is convenient to make judgment in time to control the test procedure and guarantee the safety of specimen. It is reported that the test simulation tech-

Received date: 2003-11-11; Revision received date: 2004-12-13

nologies have being researched in many fields such as flight vehicles and automobiles, *etc.*, but few complete application examples are reported in detail. The application example described in this article is the exploring research result of test simulation technology that need to be developed farther.

1 Key Techniques

The key techniques of full scale aircraft static test simulation are composed of four aspects: ①the simulation technique of aircraft structure; ② the simulation technique of system accessories such as engine, rotational operation actuator. In the full scale static test, the specimens of engine, rotational operation actuator, *etc.* are substitutes which are used to carry or transfer different kinds of internal or external loads and should be designed to have the same stiffnesses to transfere loads as the real ones. The system accessories should also be digitally simulated and integrated into the static test simulation model; ③the simulation technique of test scheme, including the test loading scheme, supporting rig of specimen; ④the technique of test *vs* analysis coherence evaluation system.

Fig. 1 shows the logical process and relationship of each technique in full scale aircraft static test digital simulation.

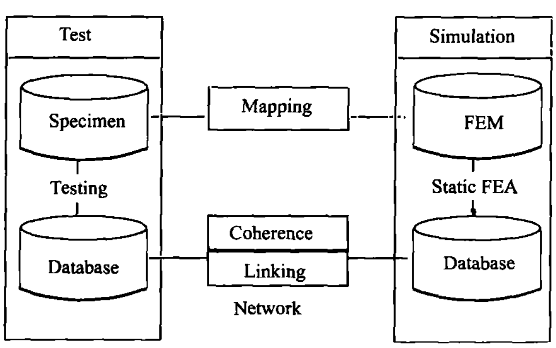

Fig. 1 Process chart of static test simulation

2 Application and Solutions

(1) The simulation technique of aircraft structure

MSC/PATRAN and MSC/NASTRAN are used to simulate and analyze the aircraft structure. For entire aircraft structure, the most important thing that should be considered is simulating properly the general stiffness of the whole structure, and the structure details are ignored in order to reduce the model size. More attentions should be paid to some kinds of special structures such as structures with open holes, access panels and connections. The rationality of stiffness simulation of these structures has a big influence on the general stiffness of aircraft, resulting in different structure deformations and stress distributions. The contour CAD database of aircraft is imported into PATRAN and GROUP function is used to assembly the entire simulation model. CONROD, BAR, QUAD4, SHEAR, HEXA elements are used for simulating frames, bulkhead, skin, stringer, beam respectively, MPC & RESPLINE are mainly used for simulating connections and assembly of different parts. Fig. 2 shows the aircraft structure simulation model which is composed of 24285 nodes, 51261 elements.

Fig. 2 Simulation model of aircraft structure

(2) The simulation technique of aircraft system accessories

The substitutes of aircraft system accessories such as engine and rotational operation actuator are used to transfer external or internal loads when the structures are being tested. For example of an engine, in flight maneuvers, the engine is subjected to loads such as inertia force, moments and thrust that will be transferred to the aircraft supporting structure through engine joints at fix points. The full scale aircraft static simulation model contains the substitute of engine. The design of substitute of engine should be considered to have the real stiffness and connection simulation. Fig. 3 shows the installation of the substitute of engine on static tested aircraft.

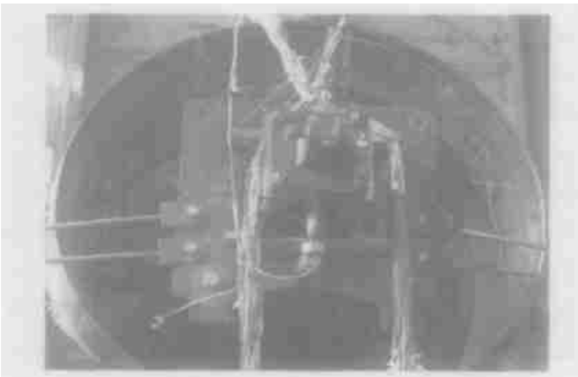

Fig. 3 Installation of the substitute of engine on static-tested aircraft

(3) The simulation technique of test scheme

In order to simulate the actual flight, the specimen of the aircraft is staticaly —determinate with suspending supports, Fig. 4 shows the support scheme. The full scale aircraft static simulation model contains the substitutes of landing gears, and the simulation model are fixed in the same way the actual testing support scheme.

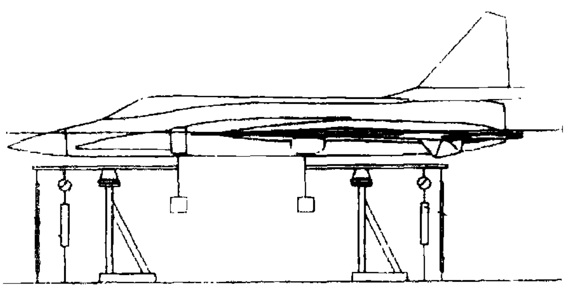

Fig. 4 The specimen support scheme

Running the simulation model with changing different loading schemes, different load cases, as a result, the optimized loading scheme and test load cases are decided finally. At the same time, the simulation database that will be tested later are established, and it is easy to predict the structure responses such as deformations and stresses in the testing load cases and to choose proper hydraulic cylinders to apply the test loads and find critical areas of tested structures that should be monitored during the test. Fig. 5 shows the structure simulation deformation when the aircraft is subjected to symmetrical dive and pull up maneuver load.

Fig. 5 The deformation of simulation test

(4) The simulation technique of test scheme

Fig. 6 shows the principle chart of quick test data coherence evaluation system. The test measuring system is linked to simulation database by network, For each loading step, the test data such as strains and displacements are imported to the simulation database, the actual stresses and deformations of the interesting points decided by static simulation before test are quickly calculated, and the coherence with simulation data and changing trend of test data are displayed on the monitoring screens. The structure deformation is monitored in the same way. The system is developed by MSC/PCL function.

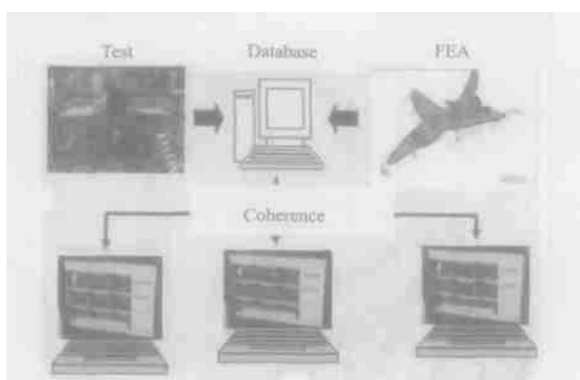

Fig. 6 The quick test data coherence evaluation system

Fig. 7 shows the monitoring display interface. It is emphasized that the test date of each loading step is integrated into the simulation database and the test procedure can be repeated any time.

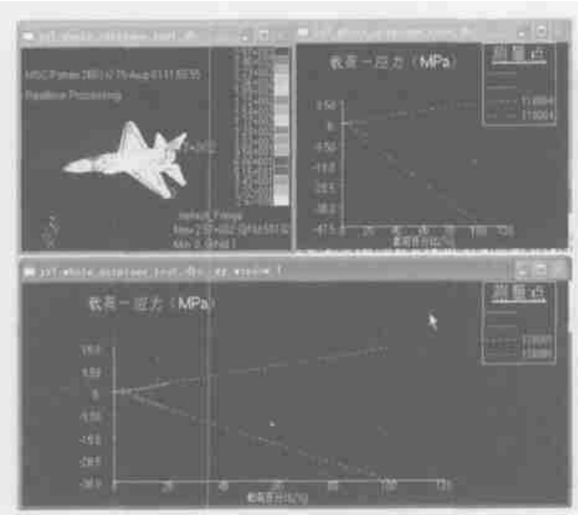

Fig. 7 Display of interface

3 Results

Fig. 8 shows the comparison of fuselage deformation between test and simulation, the error of nose point of fuselage being 1.4 mm and the rear point of fuselage 0.36 mm. The measured maximum Von. Mises stress is 712.6 MPa, the simulation stress is 677 MPa, the relative error is − 5.3%.

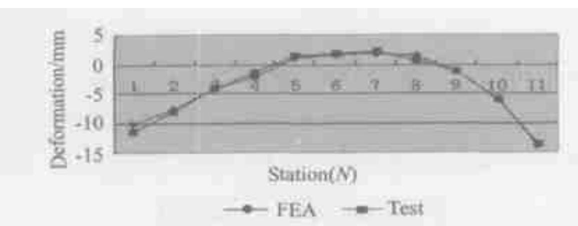

Fig. 8 The fuselage deformation comparison between test and simulation

By developing and practicing the full scale aircraft static test simulation technology, the test executing scheme is optimized. The amount of full scale static test load cases is reduced from 8 of preliminary design to 6 of actual test. Before maiden flight, for limit load test, three load cases are tested on the aircraft; the other three load cases are finished by virtual digital simulation only. Because of the application of quick test data coherence evaluation system, the efficiency has been improved greatly, and the test period has also been shortend.

4 Conclusions

Now the ultimate load static tests of full scale aircraft have been finished, the test results have proved that the application of full scale aircraft static test simulation technology is successful. With the development of such technology, most of aircraft structure static tests will be gradually replaced by virtual digital simulations in structure preliminary design stage to validate the structure layout. The amount of load cases of the full scale aircraft static verified tests of structure in finial design stage will be decreased effectively and pereplaced by digital simulations, resulting money saving and design period shortening. It has a brilliant future.

References

[1] 叶天麒, 周天孝. 航空结构有限元分析指南[M]. 北京: 航空工业出版社, 1996. 135− 185.
Ye T Q, Zhou T X. FEM analysis guide for aeronautical structure[M]. Beijing: Press of Aviation Industry, 1996. 135− 185. (in Chinese)

[2] Niu M C Y. Airframe stress analysis and sizing [M]. HongKong: Hong Kong Conmilit Press LTD, 1999.

[3] Dascotte E. Linking FEA with test[Z]. Belgium: Dynamic Design Solution, NV. Leuven, 2004.

[4] MSC. Nastran preference guide[M]. MSC Corp, 2000.

[5] MSC. Patran2000 (r2) PCL reference manual[M]. MSC Corp, 2000.

Biographies:

XU Ze Born in 1966, he received B.S. and M.S. from Beijing University of Aeronautics and Astronautics in 1989 and from Chengdu aircraft design & research institute in 1993 respectively, and then became strength engineer there. Now he is the director of strength department, professor. He is studying up aircraft design Ph.D in Nanjing University of Aeronautics and Astronautics from 2003. Tel: (028) 85509728, E-mail: 611_xuze@163.com